PROGRESS TOWARDS AN OPERATIONAL RUBIDIUM FOUNTAIN

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The U.S. Naval Observatory has an ongoing program to develop atomic fountains for eventual incorporation into the USNO Master Clock. The fountains are being constructed to provide a stable frequency reference which will allow for rapid characterization of drift of masers in our clock ensemble. In support of this goal we are using rubidium to exploit the small cold-collision frequency shift. We report on the progress made in the construction and testing of our first rubidium device.

Overview

We are nearing completion of our rubidium fountain. This device has been built with a goal of long term (10 year) operation.

This atomic fountain is designed for use at USNO and the USNO Alternate Master Clock (at Schriever Air Force Base). The physics package is contained within a frame of 0.8x0.8x1.8 meters. In addition, there are two equipment racks to house all of the lasers, optical tables, frequency synthesis, and control systems.

With most of the components in hand, we foresee preliminary operation this summer.

Atoms will be collected from background vapor and cooled in a lin⊥lin molasses. The atoms will be launched vertically along the <1,1,1> axis.

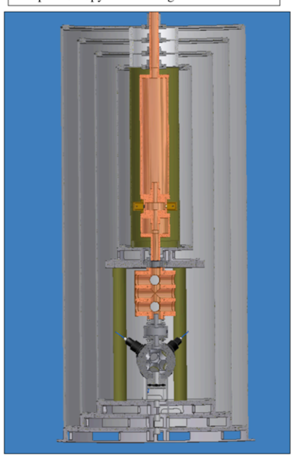
State selection will be performed with a low Q stainless steel cavity and transverse light pressure in the detection region.

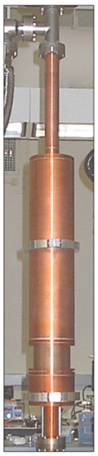
The copper spectroscopy cavity is part of the vacuum envelope and has a Q of 6,500. The cavity is fed symmetrically at its equator by two feeds with ceramic window feedthroughs.

All laser beams are formed by monolithic fiber couplers that are bolted to the vacuum envelope.

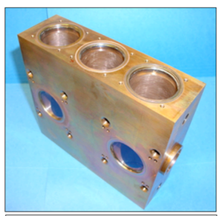
Physics Package

Cutaway view of the physics package from our CAD software. The central vacuum chamber contains (from bottom to top) a collection region, state preparation cavity, detection region, and a spectroscopy/drift tube region. The entire device is surrounded with three magnetic shields, with a fourth shield around the spectroscopy and drift region.





Copper drift tube and spectroscopy region. The microwave cavity is fed symmetrically from two sides at its equator. There are two ceramic microwave feedthroughs in the flats to the right and left in the picture.



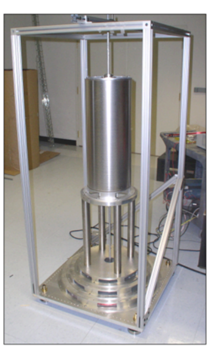
Copper detection body with e-beam welded windows. Not shown are copper/titanium explosion bonded conflat flanges that are welded to the top and bottom.

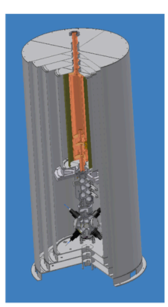
Stainless steel state preparation cavity. There is a single microwave feed through a ceramic window. The top and bottom contain conflat flanges.

Collection region (before window welding) with molasses beam couplers attached. View is from above (launched atoms would come out of the page).

Spherical collection region with e-beam welded windows.

Partial Assemblies

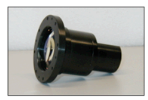




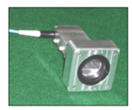
Laser and Optics

The laser source is based on frequency doubling of 1560nm light to get the 780nm light required for trapping, cooling, launching, and detection of the rubidium atoms. After performing several experiments ourselves, we contracted with a commercial company (IRE Polus Group*) to provide a high-power 780nm source of this type.

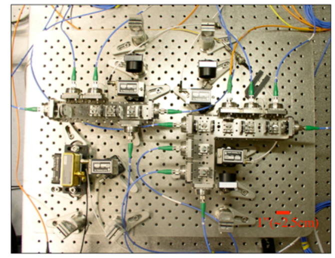
The laser is housed in a 4U high enclosure and supplies up to 1.5W of 780nm light in a single mode fiber. We are currently evaluating the laser linewidth and stability.



Molasses beam coupler



Light sheet coupler

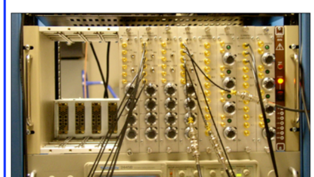


The majority of the optics are rack-mounted on a single 38x56 cm optical table. The table is built around two custom "fiber bench" tables from OFR*. A high power (1.5 W) laser source comes to the table on a single mode (PM) optical fiber. The shifted laser frequencies are generated in double-pass through AOM's and returned to the fiber bench for splitting and coupling. An EOM provides a sideband on one beam for optical pumping and repumping that is tuned to the F=1 to F'=2 transition.

This table provides 11 fiber outputs: 3 each for the upward and downward trapping/launching beams, 2 detection beams, 2 pumping/repumping beams, and an output that goes to a frequency locking setup.

The laser frequency is offset locked to a rubidium vapor cell. The spectroscopy setup is in a small rack-mounted enclosure and receives a fiber from this optical table.

Microwave Synthesis and Electronics



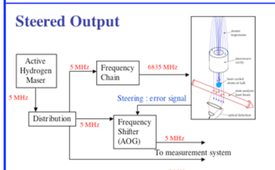
Modular electronics including general PI servos, summing junctions, and triggerable DC levels.

We are largely duplicating our previous 9.2GHz frequency chain. The chain starts with a low phase noise 5MHz BVA crystal oscillator. This oscillator is phase locked to an active hydrogen maser with a time constant of roughly 3 seconds. The 5MHz is multiplied to 40 and 100 MHz. The 100 MHz is used to phase lock a 6.8GHz Dielectric Resonator Oscillator.

The final frequency is generated by mixing the doubled output of a synthesizer (34.6x MHz) with the 6.8 GHz from the DRO. The synthesizer is clocked from the 40 MHz that is generated from the 5MHz crystal. The synthesizer allows easy phase modulation for interrogation of the atomic line.

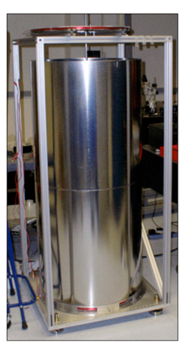
We are using fabricated circuit boards and NIM modules. Control of the fountain is mediated by a TTL pattern generation interface.

Steered Output

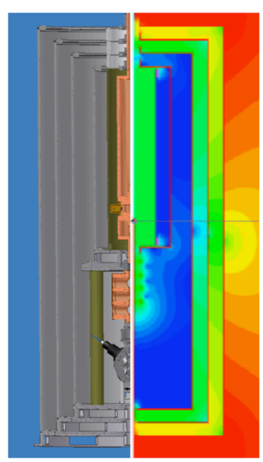


We will use the same strategy as in our previous work to produce a steered output that reflects the stability of the fountain. The fountain will monitor the frequency of an active hydrogen maser and provide corrections to a high resolution synthesizer that is driven by the same maser. The steering values are generated by a critically damped Kalman filter with outlier rejection and holdover to reduce the impact of any missed fountain cycles.

Magnetic Shields



Outer shield in the support structure



The magnetic shielding has three layers over the entire apparatus and a fourth around the free precession region.

Our models indicate a shielding factor exceeding 100,000. Measurements of individual layers have met our modeling expectations. Evaluation of the full shielding will have to be performed with the atoms.

The right hand side of the figure is a model of the magnetic field within and outside the magnetic shields.

External field: 0.5 Gauss

The central solid green region corresponds to 1mGauss and is created by the C-field winding and several bias coils wound through the detection region.

Deep blue corresponds to less than 1 microGauss. The atom collection occurs in this low field environment

* Mention of specific company names or products does not constitute endorsement by USNO